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Segmentation by single and combined features involves different contextual influences

Concetta Francesca Alberti *, Andrea Pavan, Gianluca Campana, Clara Casco

Department of General Psychology, University of Padua, Via Venezia 8, 35131 Padua, Italy

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ABSTRACT

Orientation discrimination of a texture line having orientation different from that of static background lines is facilitated when the lines are aligned along their orientation axis and when their separation is small (Experiment 1a). The facilitation by alignment remains when motion is added to the target (Experiment 1b). However, when the motion rather than the orientation has to be judged, alignment reduces sensitivity (d') regardless of whether the target has orientation the same as (iso-oriented) or different from background elements (Experiment 2). The inhibitory effect of alignment is confirmed when subjects have to discriminate the motion direction of an iso-oriented target (Experiment 3). Such inhibition by alignment is stronger when elements are close and may reflect a property of lateral interactions of motion detectors, since it is only present when observers have to judge the target motion direction. Overall, our results indicate an opposite role of the lateral interactions that facilitate grouping of iso-oriented and collinear elements, in segmentation by orientation contrast and motion contrast. In other words, global grouping (i) facilitates discrimination of orientation contrast, indicating a global process, and (ii) inhibits both detection and discrimination of motion contrast, suggesting the presence of a local process.

1. Introduction

Fragments of images are not processed in isolation, but instead are interpreted as part of a whole, global structure. The Gestalt psychologists were the first to describe the influence of global context on the perception of local features and to suggest that perceptual salience depends upon Gestalt laws of perceptual organization. According to the Gestalt laws of proximity, similarity, good continuation and common fate, some elements in an image segment from surrounding elements if they are remote from each other, dissimilar, misaligned or do not move in the same direction (Rock & Palmer, 1990). The initial outputs of low-level visual filters selective for basic features of a stimulus (e.g., spatial frequency, orientation, direction of motion and position) are insufficient to account for these visual context effects. To explain contextual influences, physiologists suggested and demonstrated that the response of cells in V1 to stimuli presented inside the classical receptive field (RF) can be modulated by stimuli laying in the surroundings of RF, while recent anatomical (Rockland & Lund, 1982, 1983) and physiological studies have investigated spatial (Gilbert, Das, Ito, Kapadia, & Westheimer, 1996; Kapadia, Ito, Gilbert, & Westheimer, 1995) and temporal mechanisms (Singer & Gray, 1995; Yen & Finkel, 1998) by which these context-dependent effects may arise in the striate cortex. It has been shown that these contextual influences can be both inhibitory and excitatory (for a review see Lamme, 2004). For example, single unit recording showed the existence of suppressive/inhibitory interactions between the classical and the surrounding RFs (Nelson & Frost, 1978; Sillito, Grieve, Jones, Cudeiro, & Davis, 1995). Although the presence of collinear flankers also acts to suppress the cell response with targets at suprathreshold contrast levels (Polat, Mizobe, Pettet, Kasamatsu, & Norcia, 1998), collinearity may produce facilitation when a near threshold stimulus inside the RF is flanked by high contrast collinear elements in the surround. However, a study of Kapadia et al. (1995) reports excitatory influences also using high contrast bar stimuli when these are co-aligned over both the classical and non-classical RF. Psychophysical studies often reported a suppressive effect of collinear flankers on contrast detection or discrimination (Snowden & Hammett, 1998; Solomon, Sperling, & Chubb, 1993). However, Polat and Sagi (1993, 1994) clearly showed increased contrast sensitivity for a target, a Gabor consisting of a cosinusoidal carrier multiplied by a Gaussian envelope, surrounded by two Gabor flankers when local and global orientations were aligned. The space constant of the Gaussian envelope (σ) was set equal to the wavelength of the carrier; this had the effect to scale the size of the Gabor as a function of the carrier's wavelength and permitted to set the target-flanker distance proportionally to the size of the Gabors. The centre-to-centre target-flanker distance was expressed in terms of multiples of the carrier's wavelength. In particular, Polat and Sagi (1993) using a low contrast Gabor vertically surrounded by two high contrast Gabors found a suppressive region

* Corresponding author.
E-mail address: concetta.alberti@unipd.it (C.F. Alberti).

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of about two wavelengths (λ) in which the presence of the flankers increased the target contrast thresholds. Beyond this range they found a larger facilitatory region up to 10λ, in which there was a decrease of the target's contrast threshold. Polat and Sagi (1993) using a wavelength of 0.15°, a spatial frequency of 6.67 cpd ($1/\lambda$) and σ of 0.15°, found a facilitation at 3λ of target-flank distance (i.e., $3*0.15 = 0.45°$) that corresponds to about 30 arcmin. Kapadia et al. (1995) also reported that observer's contrast detection for a bar was 40% improved by a second suprathreshold collinear bar at a distance of about 30 arcmin.

To summarize, there is both neurophysiological and psychophysical evidence of collinear facilitation in contrast detection of targets at both threshold and suprathreshold levels.

Contextual influences by collinear elements may also facilitate texture segmentation based on differences in orientation. Collinear facilitation by the flankers in a contrast detection task was also found when the target had to be segmented from randomly oriented background elements (Polat & Bonneh, 2000). In this case, although the background increased contrast thresholds, suppression became facilitation when two of the elements flanking the targets were made iso-oriented and collinear, even at relatively high target contrast levels (up to 40%). The distance capturing maximal facilitation was again at 3λ (corresponding to ~30 arcmin). The results outlined by Polat and Bonneh (2000) suggest that when employing appropriate distances, facilitation of texture segmentation by collinear flankers may occur when the target is defined by a relatively wide range of luminance contrast levels. The study of Polat and Bonneh (2000) is relevant because the facilitation by collinear flankers is found in a task involving both contrast detection and texture segmentation based on orientation contrast. Indeed, whereas improved detection of the isolated target indicates contrast enhancement, improved texture segmentation indicates reduced surround suppression from the randomly oriented background. In the conditions in which a facilitatory effect was found with a suprathreshold target, Polat and Bonneh (2000) measured improved target-background segmentation based on orientation contrast by the collinear iso-oriented flankers rather than contrast detection. In our recent study in which target and background elements had the same high contrast (Casco, Campana, Han, & Guzzon, 2009), we isolated the role of flankers collinearity in texture segmentation based on orientation contrast; that is, the observers' ability to discriminate the orientation of a central Gabor from a background of 45° oriented Gabors was found to increase when the target was flanked by two iso-oriented and collinear flankers compared with flankers iso-oriented and non-collinear or else ortho-oriented.

In addition to the facilitation of texture segmentation induced by flankers collinear with respect to the target, the facilitatory effect may be investigated by manipulating the collinearity of the background elements (i.e., the texture region). There is wide evidence that alignment of elements in the texture region also facilitates segmentation based on orientation contrast in several tasks: localization of differently oriented texture element (Meigen, Lagreze, & Bach, 1994), discrimination of a texture boundary (Giora & Casco, 2007) and of a texture figure (Casco, Campana, Grieco, & Fuggetta, 2004; Casco, Grieco, Campana, Corvino, & Caputo, 2005; Harrison & Keeble, 2008). Such facilitation from the region poses problems of establishing whether collinearity is a background or a target-to-background feature. Indeed, the facilitation by collinearity may occur both from elements near the target and from those in the texture region – where iso-oriented and collinear elements form perceptual structures that may facilitate segmentation based on orientation contrast. Studies by both Giora and Casco (2007) and Harrison and Keeble (2008) have shown a specific effect of the facilitation from the region, independent of that produced by target-to-flanker lateral interactions.

To summarize, previous studies show that flankers iso-oriented and collinear with the target facilitate its segmentation from the surrounding texture region. This may reflect the role of collinearity in increasing the saliency of the target as a consequence of the reduction of surround suppression by iso-oriented background elements. Moreover, segmentation based on orientation contrast may also be facilitated by the alignment of element in the far texture region.

In the present study we asked whether background collinearity could facilitate the target-to-background segmentation, both when the segmentation was based on motion contrast and on superimposed features-contrast, such as orientation and motion. To this purpose we compared contextual influences when background elements and target where aligned (collinear) and when they were misaligned (non-collinear), in three conditions of features-contrast: (i) when target saliency was due to orientation contrast alone; (ii) when target saliency was due to orientation and motion contrast; (iii) when target saliency was due to motion contrast alone. Thus, in our Experiments collinearity was both a background and a target-to-background feature.

Although contextual influences have been shown in neurons selective for both orientation and motion direction (Akasaki, Sato, Yoshimura, Ozeki, & Shimegi, 2002; Jones, Grieve, Wang, & Sillito, 2001; Kastner, Nothdurft, & Pigarev, 1997; Walker, Ohzawa, & Freeman, 1999), investigation to date has been limited to the inhibitory effect of a surround drifting in the preferred direction (Walker et al., 1999) and partially in the non-preferred direction (Jones et al., 2001). These results show that the presence or absence of figure-ground segregation due to either a difference of orientation or motion direction is critical for the strength of surround suppression (Akasaki et al., 2002). To our knowledge, the issue of whether discrimination of motion contrast can be modulated by features-alignment has never been studied. A modulation, however, is not unlikely since Kapadia et al. (1995) found that the detection enhancement at optimal coaxial separation was reduced considerably by applying a lateral offset of as little as 10 arcmin; this could suggest an inhibitory effect of alignment in motion detection since motion also produces a lateral offset.

We compared the effect of contextual influences by non-collinear and collinear background elements that form 45° oblique, collinear structures on various different tasks, considering not just texture segmentation based on orientation contrast (Experiment 1a) and motion contrast alone (Experiment 3), but also measuring orientation discrimination with a target defined by superposition of orientation and motion (Experiment 1b) and motion detection of a target similarly defined (Experiment 2). Moreover, we also asked whether the effect of alignment was different for small and large separations between elements. The seminal work of Gestalt psychology (Wertheimer, 1923) threw light on the role of elements separation on perceptual integration of texture elements into perceptual structures. The issue is still relevant because studies in recent decades have shown that inter-element spacing affects texture segmentation (Nothdurft, 1985) in addition to contrast detection. In addition, studies have shown that contrast enhancement by collinear flankers occurs only within a restricted inter-element separation of 20–30 arcmin (Polat & Bonneh, 2000, 1993, 1994; Polat et al., 1998).

2. General method

2.1. Apparatus and stimuli

Stimuli were generated by a Cambridge Research System VSG graphics card with 12-bit luminance resolution, and displayed on a gamma-corrected Sony monitor with a resolution of